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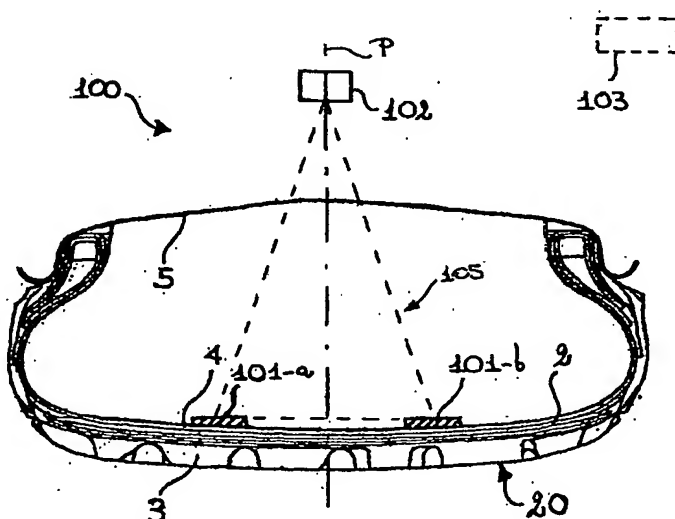
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(54) Title: METHOD FOR MONITORING TYRE DEFORMATIONS AND MONITORING SYSTEM THEREFOR



(57) Abstract: It is disclosed a method and system for monitoring deformations in a tyre of a vehicle wheel, the wheel comprising the tyre and a rim. The method comprises the steps of: a) providing the wheel with at least two magnetic field emitters (101-a, 101-b) in mutual positions so as to yield a composite magnetic field having at least a space portion where at least a component of the composite magnetic field is substantially null, at least one of the at least two magnetic field emitters being positioned in contact with the tyre; b) positioning at least one main magnetic field sensor (102) substantially in said space portion; c) monitoring variation of said at least one component of the composite magnetic field; and d) correlating said variation with tyre deformations.

## METHOD FOR MONITORING TYRE DEFORMATIONS AND MONITORING SYSTEM THEREFOR

The present invention relates to a method for monitoring tyre deformations and to a corresponding monitoring system.

5 As it is known, tyre deformations are induced by the interplay of lateral or longitudinal forces produced by the motion itself of a motor vehicle and friction of tyres with the road. Deformations represent a viable way for monitoring relevant parameter such as slipping angles, flattening and, generally speaking, variations in the footprint area of a  
10 tyre, which control the adhesion and friction of a tyre with the road. In turn, such detected information can be useful to prevent critical situations, thus improving the whole safety level of vehicles.

A number of different systems and methods have been proposed for measuring the tyre deformations. These methods are based upon  
15 direct measures of twisting forces or upon coupling of suitable signal generators with sensors capable to measure these signals.

Among them, magnetic systems (see, for instance, EP 1 289 813, and US 5 964 265) have been proposed.

EP 1 289 813 (in the Applicant's name) discloses a system for  
20 monitoring the shear deformations of a crown portion of a tyre during the running of a motor vehicle. It comprises at least one magnetic field (hereinafter also referred to as MF) generator, preferably a strip of magnetic material applied to the tyre, and at least a sensor strip measuring the MF variations of said MF generator. Each magnetic  
25 generator generates a magnetic field of intensity which is detected by the corresponding magnetic induction sensor. The monitoring of the tyre deformations is effected by measuring the variation in time of the magnetic field produced by the MF generator during the running.

US 5 964 265 (in the name of Continental Aktiengesellschaft) dis-  
30 closes a system for determining tyre-road adhesion. The system is

composed by a subsystem for generating data comprising a magnetic sensor and a magnetic field produced by partial magnetization of the belt in radial direction. Such belts can contain ferromagnetic powders to increase the MF produced. The sensors are placed within the tread.

5 US 6 404 182 (in the name of Canon Denshi) discloses a system for detecting the revolution of tyres using a magnetic field. In an embodiment the tyre steel belts performs as MF generator, being uniformly magnetized in a direction for a portion of the circumference and in the opposite direction for the other portion of the circumference. Another  
10 embodiment consists in providing a magnetic member inside the wheel. The magnetic field generated, for example, by the magnetized steel belt is detected by two magnetic detection elements, which are set so that the magnetic field detection directions of the two magnetic detection elements are parallel to the side surface of the tire, and the  
15 two elements are juxtaposed in a direction perpendicular to the side surface of the tire. Said detection elements are provided in the vicinity of the tyre, in a fixed position, for example on the side of a seat.

US 5 670 877 (in the name of Hughes Electronics) discloses a method and apparatus for sensing rotation of shafts. It comprises two  
20 magnetic sensors disposed with respect to a rotating magnetic source, which is integral with the shaft itself, to sense the MF components that are generated. The magnetic generator is a magnet positioned along a part of the shaft with a north and south pole. Under rotation of the shaft a waveform signal is produced with a periodically variable magnetic  
25 field. Measuring the period of revolution and the variation of these periods results in information on the acceleration and velocity during the shaft revolution. Possible applications are ABS systems.

The systems disclosed by the above mentioned documents provide partial information about the deformation of a tyre.

30 In the case of US 6 404 182 and US 5 964 265 the magnetization

of the steel belt of the tyre can provide information about deformation just in running conditions. Analogous consideration may be applied to US 5 670 877.

Also in the case of EP 1 289 813 the information collected is not satisfactory. The system therein disclosed is based on MF generator/sensor units operating independently from one another, i.e. each sensor detects MF variation from a single generator. This results in a mono-dimensional reading of the magnetic field because only the intensity modulus is measured.

Applicant perceived that the need for a method and system for monitoring the deformations of a tyre being sensitive and reliable, thus capable of detecting even small deformations, advantageously in the three spatial directions, was still felt. Also, such a system and method should be simple and easy to be manufactured/performed.

Applicant found that an effective monitoring of the tyre deformations can be achieved by measuring the vectorial components of a composite magnetic field associated to the tyre and establishing a simple relation, for example a linear or quadratic relation, between MF vectorial variations and tyre deformations. A method for measuring the MF vectorial components was found based on detecting the state of a composite magnetic field generated by at least two emitters.

In a first aspect the present invention relates to a method for monitoring deformations in a tyre of a vehicle wheel, the wheel comprising the tyre and a rim, the method comprising the steps of:

a) providing the wheel with at least two magnetic field emitters in mutual positions so as to yield a composite magnetic field having at least a space portion where at least a component of the composite magnetic field is substantially null, at least one of the at least two magnetic field emitters being positioned in contact with the tyre;

b) positioning at least one main magnetic field sensor substantially

in said space portion;

c) monitoring variation of said at least a component of the composite magnetic field by means of said at least one main magnetic field sensor; and

5 d) correlating said variation with tyre deformations.

For the purposes of the present invention, "composite magnetic field" means a magnetic field resulting from the interaction of the magnetic fields generated by at least two MF emitters.

The method according to the invention is based on the displacement of the composite magnetic field (MF) space portion wherein at least one component of said MF is substantially null.

As at least one of the MF emitters is positioned in contact with the tyre, tyre deformations move such emitter and, as a consequence, produce said displacement.

15 The at least one main sensor positioned in said space portion detects changing of the at least one MF component, which is related to the deformation of the tyre, by, for example, a linear or quadratic relation.

More preferably such space portion includes a special space portion (SSP) which is a sub-portion where all the components of the magnetic field are substantially null, and the at least one main sensor (hereinafter also referred to as "main MF sensor" or "main sensor") is therein positioned.

25 Preferably, the method of the invention provides monitoring of the tyre deformations in the three spatial directions.

The detection sensitivity is higher and more reliable than that of the known systems in view of various features, for example, the mutual positioning of the at least two emitters of magnetic field and the at least one main sensor, said positioning being substantially triangular. Such positioning yields a composite magnetic field distributions varying in

the three spatial directions around the space portion where the main sensor is substantially located. Also, variations of the MF components are expressed by simple linear or quadratic laws as a function of the relative displacement of at least one of the at least two MF emitters, which is caused by the tyre deformation. Hence, the deformations can be effectively monitored in one or, preferably, all of the three spatial direction (lateral, longitudinal or vertical). The magnetic field variations are monitored by the main magnetic sensor whose response is typically unisotropic and linear with the magnetic field. Measuring variations of said magnetic field components results in detecting and monitoring the corresponding deformations which induce such variation in terms of the relative displacement of the magnetic field emitters with respect the main sensor.

In another aspect, the present invention relates to a system for monitoring deformations in a tyre of a vehicle wheel comprising:

- a) a wheel including the tyre and a rim;
- b) at least two emitters of magnetic field positioned in the wheel in mutual positions so as to yield a composite magnetic field having at least a space portion where at least a component of the composite magnetic field is substantially null, at least one of the at least two magnetic field emitters being positioned in contact with the tyre;
- c) at least one main magnetic field sensor placed substantially in said space portion.

Preferably, at least one of the at least two emitters of magnetic field (hereinafter also referred to as "MF emitters" or "emitters") is positioned in the crown portion of the tyre.

Preferably, at least one of the at least two MF emitters is placed in a radial internal position with respect to any tyre metal structure, typically the belt or the carcass. For example, it can be applied on the liner. Another emitter of magnetic field can be placed on the rim.

Preferably, at least two emitters are positioned in contact with the tyre.

Preferably, the at least two emitters of magnetic field are elongated elements, for example in form of tapes, disposed substantially along a circumference of the wheel. Each of the MF emitters can be either in a  
5 single piece or in multiple pieces.

For example, an MF emitter can be about 1-3 cm large. It can be about 0.1-0.3 cm thick.

An MF emitter can be made up of tapes (for instance about 10-20  
10 cm long), which can be aligned or juxtaposed to form a longer tape. This solution is preferred for adapting the MF emitter to any kind of tyre size.

Advantageously, the MF emitters are manufactured by extrusion of vulcanizable blends including at least a magnetic or magnetizable material, for example a powder.  
15

Preferably, the MF emitters are made directly on the tyre during the manufacturing thereof, the whole assembly being vulcanized thus fixing the MF emitters in the tyre, and finally the magnetic field emitters are magnetized according to known methods, for example by using a solenoid or a magnet.  
20

More preferably, the magnetic field emitters are provided in the tyre during a manufacturing process wherein at least one element of the tyre is built-up by depositing, for example by extrusion, an elongated element in raw elastomeric material according to a predetermined path.

25 A work station suitable for such manufacturing process comprises a robotized arm, preferably of anthropomorphic type. Preferably such robotized arm maneuvers a substantially toroidal rigid support where the deposition of the elongated element is effected. Reference is made to patent applications WO 00/35666 and EP 0 928 680 in the Applicant's name that are incorporated herewith as references.  
30

In another embodiment, MF emitters and tyre are prepared and vulcanized separately, then the emitters are magnetized and successively fixed upon the tyre with suitable means, for example with an adhesive material or a low temperature cross-linkable rubber.

5 In a further embodiment, already magnetized emitters are extruded in a green tyre or applied thereupon, then the whole is vulcanized.

Advantageously, the at least two magnetic field emitters are made of magnetic rubbers comprising a polymer or a polymer blend, and at least a magnetic material.

10 Preferably, said polymer or polymer blend has an elastic modulus at least 10% lower than the elastic modulus of the liner. They can be selected from halogen-butyl rubbers, for example halogenated isobutylene-isoprene (IIR) rubber.

The at least a magnetic material can be present in the magnetic rubber in an amount ranging from about 50 to about 400 phr.

15 The at least a magnetic material can be hard magnet material, for example NdFeB, NdPrFeB, SmCo, Alnico 5 and Alnico 9.

Magnetic materials having an isotropic magnetization are preferred.

20 Magnetic materials with an intrinsic coercivity of at least 100 kA/m are preferred in order to prevent accidental demagnetization of tapes and instability with time. For instance, NdPrFeB has an intrinsic coercivity ( $H_c$ ) of 740 kA/m. Nevertheless, use of less coercive materials like Alnico 5, which have typically a  $H_c$  of about 50 kA/m, is acceptable especially in combination with a magnetic lens, as discussed hereinbelow.

25 Preferably, the at least a magnetic material has a residual induction ( $B_r$ ) higher than 0.6 T (Tesla). This characteristic allows lower amount of magnetic material present in the magnetic rubber, thus improving mechanical properties of the emitters and, in the case, the

30



compatibility with other tyre materials.

Preferably, the at least a magnetic material has a Curie temperature (the temperature above which a ferromagnetic material loses its permanent magnetism) significantly greater than the temperature of use  
5 of the tyre. The Curie temperature should be significantly greater than the manufacturing temperature of the tyre, when the MF emitters are built in the tyre in a magnetized form. Advantageously, the Curie temperature is greater than 300°C.

The MF emitters can be magnetized uniformly or a magnetization  
10 modulation can be induced, for example through a different intensity and/or direction magnetization. When an MF emitter is composed by more than one piece, each piece could be magnetized as the others or a magnetization modulation could be induced, for example through a different intensity and/or magnetization direction of each piece.

15 The MF emitters can generate a composite magnetic field having an intensity ranging, for example, from about 0.01 G to about 10 G (gauss).

The method and system of the present invention can advantageously comprise at least a magnetic lens. Said magnetic lens can be  
20 useful to deflect the composite magnetic field generated by the MF emitters so as to "concentrate" the composite magnetic field in a radially internal direction. Moreover the magnetic lens may provide a screen from external magnetic fields

The magnetic lens can be placed in a circumferential and radially  
25 external position with respect to the MF emitters, and in radially internal position with respect to any tyre metal structure.

The magnetic lens comprises soft magnetic material characterized by low values of coercive field, for example, equal or lower than 80 A/m. Examples of soft magnetic materials are soft ferromagnetic  
30 materials, e.g. pure iron, permalloy and supermalloy.

Such soft magnetic material can be mixed in rubber material. Preferably the amount of said soft magnetic material is of about 50-100 phr, more preferably 10-30 phr.

A magnetic lens can be provided for each emitter, being wider than it. Preferably a single magnetic lens, suitably wide, is provided for the at least two magnetic field emitters.

The thickness of the magnetic lens can be of at least 0.05 cm, for example of about 0.1-0.5 cm.

The magnetic lens can be produced in manners analogous to those described for the magnetic field emitters.

Preferably the at least one main magnetic field sensor is positioned in a non rotating portion of the wheel.

Preferably, said at least one main sensor is positioned substantially in a space portion where all the components of the composite magnetic field are substantially null. More preferably, it is positioned in a special space portion as described above.

The method and the system of the present invention may further comprise at least a secondary magnetic field sensor. This secondary sensor is useful for monitoring magnetic signals deriving from sources other than the at least two magnetic field emitters, and subtracting them from the reading of the main sensor.

A secondary sensor can be located at least 20 cm far from the at least a main sensor. This positioning is advantageous for removing signals induced by the terrestrial magnetic field.

Alternatively or additionally, a secondary sensor can be located at a distance smaller than 3 cm from the corresponding at least a main sensor. This positioning is advantageous for removing signals induced by metal portion, for example, of the wheel or of the tyre itself.

Preferably, secondary sensors are provided in both the just above mentioned configuration.

A single secondary sensor can be provided for multiple main sensors.

Each main and secondary sensor can be either monoaxial, bi-axial or tri-axial, i.e. receptive to one, two, or three components of the MF parallel to the active axes of the sensor itself. Preferably, said secondary sensor is oriented substantially analogously to the corresponding main sensor/s. Preferably said secondary sensor is positioned on a non-rotating portion of the wheel.

Both the at least one main sensor and the optional at least a secondary sensor can be positioned in a radially internal position with respect to the tyre. Possible convenient locations could be the steering gear or shock absorber block, or the braking block of the vehicle.

The at least one main magnetic sensor and the optional at least a secondary magnetic sensor can be commercially available magnetic sensors like Hall or fluxgate sensors, or, preferably, linear magnetoresistive sensors.

The system of the invention can be connected to on-board computers or other electronic equipments of the vehicle via electronic means. Examples are illustrated in the patent application WO99/29522.

Advantageously, the method and system according to the present invention can be used to monitor any kind of tyre deformations, i.e. lateral deformations, vertical deformations and longitudinal deformations. These deformations can be monitored separately or as a whole. They can be used to monitor the dynamic motion of tyre, its accelerations and deceleration.

Examples of lateral deformations are those resulting during the cornering of vehicle (shears) which induce slipping and lost of adherence.

Examples of vertical deformations are those resulting from the degree of the flattening or from the lifting-up of the vehicle.

Examples of longitudinal deformations are those resulting from the vehicle braking, acceleration or deceleration.

The present invention will be further illustrated hereinafter with reference to the following examples and figures, wherein:

- 5 - Fig. 1 is a perspective view of a tyre part of a system according to the present invention;
- Fig. 2 is a cross-sectional view of the tyre of Fig. 1 mounted on a rim;
- Fig. 3 is a schematic view of a first embodiment of the system according to the present invention;
- 10 - Fig. 4 is a schematic view of a second embodiment of the system according to the present invention;
- Fig. 5 schematically depicts a composite magnetic field of the invention (example 1);
- 15 - Fig. 6 shows a space portion according to the invention (example 2);
- Fig. 7 shows the contribution of magnetic tapes as a function of angle;
- Fig. 8 is a schematic view of a third embodiment of the system according to the present invention;
- 20 - Fig. 9 is a schematic view of a fourth embodiment of the system according to the present invention;
- Figs 10A-D are schematic representations of different magnetization embodiments of the system according to the present invention; and
- 25 - Fig. 11 is a block diagram of the whole system according to the present invention.

Figures 1 and 2 show a tyre 1 for a motor vehicle having a carcass 2 and a crown 20 comprising a tread 3 in its radially outer part. A liner 4 is provided in its radially inner part. The tyre 1 is fitted on a rim 5 (partially shown in Fig. 2).

According to the present invention, tyre 1 is part of a system 100 for monitoring its deformation.

In the embodiments depicted in Figures 3 and 4, the system 100 comprises two magnetic field emitters 101-a,b on liner 4 of the tyre 1 and a main sensor 102 for the composite magnetic field (not illustrated) generated by said emitters 101-a,b.

The two magnetic field emitters 101-a,b are tapes of composite magnetic rubber arranged substantially circumferentially on the liner 4 as shown in Figures 1-4.

The system 100 comprises a main sensor 102 and, optionally, a secondary sensor 103 differently located, as shown in Fig. 3 and 4. In the embodiment depicted by these figures, the main sensor 102 is symmetrically located with respect to the emitters 101-a,b, providing a triangular arrangement 105. In Fig. 4 a magnetic lens 104 is shown.

In the embodiment shown in Fig. 8, a first MF emitter 101-a is arranged on the tyre and a second emitter 101-b is arranged on the rim. In this figure, two space portions 106, 106' are illustrated. The main sensor (not shown for sake of clarity) is arranged in the special space portion 106, for instance by connecting it to a bracket or the like connected to a non rotating portion of the vehicle, for instance the braking block 110.

In the embodiment of Fig. 9, two MF emitters 101-a,b are symmetrically arranged on the tyre and a third MF emitter 101-c is arranged on the rim. Such an arrangement provides two space portions 106 near the rim, and a third space portion 106' on the tyre. A main MF sensor (not shown for sake of clarity) can be arranged in either one of the space portions 106, again by a bracket or the like connected to a non rotating portion of the vehicle, for instance the braking block 110.

An optimal location for the MF sensor 102 can be selected considering one or more of the following features: the mutual distance and

positioning of the magnetic field emitters 101, the presence of the magnetic lens 104 which can be provided under the two emitters 101-a,b (as from Fig. 4) or embedded under the liner, the magnetization characteristics of the MF emitters.

5 In the present description as "radial component" is meant the composite magnetic field component directed radially to the tyre, i.e. perpendicular to the crown portion of the tyre. It corresponds to a vertical deformation of the tyre. As "axial component" is meant the composite magnetic field component parallel to the crown portion of the tyre and  
10 orthogonal to the vehicle running direction. It corresponds to a lateral deformation of the tyre. As "longitudinal component" is meant the composite magnetic field component parallel to the crown portion of the tyre and to the vehicle running direction. It corresponds to a longitudinal deformation of the tyre.

15 According to the above conventions, an uniaxial main sensor can be useful for pressure or vertical load sensing purposes and can be oriented for measuring the radial component of the composite magnetic field.

A biaxial main sensor can be suitable for measuring, for example,  
20 radial and axial components of the composite magnetic field, the measuring of the variations of said components being useful for monitoring deformations of the tyre running along a bend. The measuring of the radial and longitudinal components can be useful for monitoring deformations of a tyre while braking.

25 A triaxial main sensor provides a three-dimensional monitoring of the tyre deformation.

The contextual measure of magnetic field components, especially in case of lateral tyre deformations involving displacements of the at least a magnetic field emitter in the crown portion of the tyre with re-  
30 spect to the sensor, provides a complete and reliable monitoring of the

tyre status.

The method and system according to the present invention allows to establish a univocal relationship between variations of the MF components and change of position of the emitter/s with respect to the sensor.

For example, in the case of lateral deformations, the axial and radial components of the composite magnetic field in the position where the at least a main sensor is located are known and indicated as  $B_{\text{radial}}$ ,  $B_{\text{axial}}$ . When a deformation occurs, the sensor measures different value for the axial and radial components,  $B_{\text{radial}}^c$ ,  $B_{\text{axial}}^c$ , respectively. The following two equation system correlates components  $B_{\text{radial}}$ ,  $B_{\text{axial}}$  with  $B_{\text{radial}}^c$ ,  $B_{\text{axial}}^c$

$$\begin{cases} B_{\text{radial}}^c = B_{\text{radial}}(d_{\text{radial}}, d_{\text{axial}}) \\ B_{\text{axial}}^c = B_{\text{axial}}(d_{\text{radial}}, d_{\text{axial}}) \end{cases}$$

wherein:

$B_{\text{radial}}^c$ ,  $B_{\text{axial}}^c$  are the component values measured during deformation;

$B_{\text{radial}}$ ,  $B_{\text{axial}}$  are the component values of the special point where the at least a main sensor is positioned; and

$d_{\text{radial}}$ ,  $d_{\text{axial}}$  are the relative coordinates of displacement of the at least one emitter.

By inverting the equation system, the relative displacements can be calculated from the values of the magnetic field components. Hence the deformations be determined through the related magnetic field variations.

Fig. 11 shows a block diagram of the main components forming the system 100 according to an embodiment of the present invention. It comprises a sensing stage, an amplification stage, an A/D conversion stage and a processing stage, which represent the four levels of operation of the system itself:

Sensing stage, namely main sensor 102 and, optionally, secondary sensor 103: for instance, magnetoresistive bi-axial sensors by Honeywell, model HMC 1022 or HMC 1052.

Amplification stage, amplifier 107 and, optionally, amplifier 109: standard operational amplifiers, preferably with gain as large as 90.

Digital Conversion, A/D converter 111: an A/D card is used. Advantageously, a 16bit-40kHz card can be used but other formats are suitable (8 bits-12bits, etc.) depending on the compliance requirements of the electronic equipments of the vehicle. Other electronic components can be used, like PIC (Programmable Integrated Circuits) with A/D conversion capabilities.

Processing stage: It comprises electronic circuits including a processing units like a PIC. A 20 MHz-10 bit model by Microchip was used in the examples of the invention. In this stage, the digital signal from A/D stage is transformed in the corresponding magnetic field variations and is finally transformed in information about the deformations.

The sensing and amplification stages can be carried out by single sensing units comprising a sensing element (sensor) and an amplifier. Optionally they include a Set/Reset circuit to reset the units in case of failure due to, e.g., excess of temperature (for example, higher than 80°C) or a too high magnetic field (for example, greater than 20 G), or to periodically reset the main and the optional secondary sensor.

According to the present invention, amplification of the signals for the different MF components are divided into distinct channels for each active components of the main sensor (e.g. two for biaxial sensors). A similar unit is provided for all the sensing units, i.e. the main and the optional secondary sensors.

In the embodiment depicted in Figure 3 where a main and a secondary sensor 102,103 are provided, two signals 108, 110 coming,



respectively, from main sensor 102 and secondary sensor 103 enter the A/D card 111 through different channels. For example, in case of biaxial sensors, four different channels of the A/D card will be used for each of the main sensors and the secondary sensors. In the case of a four-wheeled vehicle wherein each wheel has a couple of main/secondary sensor, sixteen channels will be employed, although the use a lower number of reference sensing units, e.g. only one for all the wheels, or at least a couple, one for the front wheels and one for the rear ones, can be provided.

The signals entering each of the said channels are digitalized separately and transformed in the processing units into MF, exploiting the linear behavior of the sensing units in the whole interval of frequencies between 0 and 20 kHz.

Once this step is completed, in case a secondary optional sensor is provided, the MF component reading coming from the main sensors and the optional secondary sensor are subtracted in order to keep only the contribution from the deformations of tyres. Finally, the signals are converted in information about tyre deformations by exploiting the algorithms previously outlined for the region around the special point. This can be done both by the PIC (or A/D Card) thanks to the simple laws describing the changes of MF components, which in turn are consequence of the triangulation scheme, or can be subsequently done by a microprocessor. In any case the signals are ready to be used by a microprocessor 113 controlling the flux of data to monitor the status of the vehicle in real time, for example process during a braking in ABS systems.

#### Example 1

A system according to the invention comprised two tape-shaped MF emitters arranged symmetrically with respect to a main MF sensor, the MF emitters being applied on the liner of a Pirelli Euforia 205/45

R17 tyre. The MF emitters were composed by halogen-butyl rubber and NdPrFeB hard ferromagnetic powders, provided by Magnequench Inc., whose mean particle size was about 40  $\mu\text{m}$ , in an amount of 200 phr of ferromagnetic part. MF emitters were about 2 cm large, about 0.15 cm  
5 thick and  $2\pi R$  long, R being the internal radius of tyre measured at the liner. They were magnetized vertically with respect to the main surface with a MF at saturation as large as 3 Tesla, before placing them inside said tyre.

In order to optimize the disposition of said tapes and their physical  
10 parameters, the composite magnetic field of the system was reproduced by computer simulation using codes based upon Finite Element Method (FEM) applied to Maxwell equations. In particular an Open Source code Fernm 3.1 (BerliOS) and commercial code Opera 2D/3D (Vector Field) were employed.

15 In Fig. 5 the results of the simulation are shown (Fig. 5 representing a section of the magnetic field distribution along a plane cutting the tyre in a frontal direction and passing through the point of contact of tyre with road). The two tape-shaped emitters were magnetized radially and disposed with parallel magnetization axes. The  
20 tapes were circumferentially positioned in radial internal positions with respect to tyre liner and separated by a distance of about 12 cm. Both tapes were symmetrically disposed with respect to the sensor position as shown in Fig. 3 according to the proposed triangulation scheme.

Two symmetric space portion appeared because of the  
25 symmetrical disposition chosen. A common visual code was applied in Fig. 5 in order to make more evident the nature of this special points. Level lines represent different values of magnetic fields within the interval 0-5 Gauss. Locally, the magnetic field directions are orthogonal to the tangent line of the line level, therefore information concerning  
30 magnetic field vectors is provided by these level line visual code.

Region of high density of lines represent regions of high values of variations of the magnetic field, low ones represent regions of low variation. The space portions wherein at least a component of the composite MF is substantially null are encircled by concentric level lines. The presence of symmetry axes around such portions, along with components of the magnetic field substantially null (the vertical component, in the present case) can be easily recognized. Two special space portion SSP 106, 106' were generated where the magnetic flux was substantially null. Referring to Figures 10A-10D, such portions SSP are distributed along a circle at the same distance from the center of the tyre 1, owing to the cylindrical symmetry of the arrangement.

Similar effects appeared also in the case of two emitters 10-a,b axially magnetized, and positioned in the same geometry with their magnetization axes parallel. The main difference was a global rotation of the MF components of 90°. It resulted in the space portion 106 depicted Fig. 6 where the main sensor 102 was positioned, and in a space portion 106' (not illustrated) in a radially external position with respect to the tyre. The sensitivity of the sensor upon deformations is high as the MF variations of MF are considerable even for deformations of few centimeters or less, changing completely the MF direction, e.g. from radial to axial or longitudinal (depending upon the deformations involved).

The above equations can be used to count tyre deformations. Under a deformation of the tyre, variation in the geometric symmetry of the system according to the invention (displacement of emitter/s with respect to the main sensor) takes place. Such a displacement can be considered as a rigid displacement of the emitter/s plus minor deformations. Accordingly, a correspondent rigid shift of the magnetic field produced by a portion of the emitter/stapes is expected. The aforementioned quadratic or linear laws, as a function of such relative displace-

ments, should apply to account for MF variations due to the tyre deformations.

Fig. 7 shows the contribution to the MF components measured by the main sensor coming from different portions of the emitters, and assuming angle zero for the portion closer to the road. The portion between about  $-20^\circ$  and  $+20^\circ$  is in the footprint area and is substantially the region interested to major distortions. The plot of Fig. 7 demonstrates the effectiveness of the scheme of monitoring deformations of the area in contact with the road. Furthermore, as illustrated in Fig. 6, the spatial region around said space portion 106, where the main sensor is positioned, is subdivided in four distinct areas, each characterized by different signs and values for the MF components. Each deformation (in case of lateral deformations, for example) can be determined univocally measuring at least the axial and radial components of the MF and inferring, by a suitable algorithm, the correspondent axial and radial displacements that have produced such a MF variation.

The results of the simulations were experimentally verified using the same geometry (distances, dimensions etc.) and magnetization used for the simulations in order to make a comparison. Measures were done using a high precision gaussmeter F.W.Bell 4048, having a Hall sensor probe with a precision of about  $\pm 0.1\text{G}$  for MF intensities of few Gauss. Experimental values of the displayed components were subtracted of the correspondent value of terrestrial MF in order to make a direct comparison and mimic the effect of sensor 103. The comparison reproduced the theoretically predicted MF distributions around the special space portion 106.

Finally, the thermal stability of magnetization in tape-shaped emitters was tested. No evidence of variations in the magnetization was found even after 24 hours of thermal treatments for each measured

temperature. Measures were taken at room temperature after extraction from oven, cooling down the emitters to room temperature and measuring their surface MF. Irreversible losses of few percent (5-10%) were observed only above 150° C, depending on the properties of polymer and, in a minor amount, on the hard ferromagnet NdPrFeB. No evidence of changes in the magnetization axis was found at any investigated temperature value.

#### Example 2

A test was made substantially analogously to that of Example 1, but using a different tyre, model "PZero Rosso 225/45 R18", and a magnetic lens. This lens was about 0.1 cm thick, 18 cm large, stretching for the whole surface in a radially external position with respect to the belt. It was made of the halogen butyl rubber of the tape-shaped emitters, and pure iron powders therein dispersed in a percentage by weight of 20 phr with respect to the rubber. The resulting MF distribution was computed using the same computational tools of example 1, with a similar magnetization and disposition of the tape-shaped emitters, but with a distance between the tape-shaped emitters increased to 14 cm.

Two major changes were observed: first, the number of space portion was reduced to one in the 2D plot of MF distribution, being maintained only that located in a radially internal position with respect to the tyre (corresponding to 106 in Fig. 5). Second, the position of such space portion was raised. Both effects were induced by the screening effect and MF deflection of the magnetic layer.

#### Example 3

A test was effected substantially as in example 1, but with a bi-axial main sensor oriented in order to measure the vertical and longitudinal components of the MF. Such set-up is effective in application with ABS systems, especially when a modulation in the magnetization along the

emitters is induced.

Upon a braking, both a vertical and a longitudinal deformation appeared. Components of the MF along those directions measured by the main sensor grew accordingly, being zero at unstrained conditions.

5 Such deformations were the results of the inertial forces due to the deceleration process and the grip of the tyre with the road.

The measure of the longitudinal deformation is an indirect measure of such grip or more in general of the grip conditions. In particular, should an estimate of the grip be an issue, it can be evaluated by  
10 coupling an accelerometer, which measures the value of the inertial forces, or any other means capable of measuring the deceleration forces, with the system 100, which monitors the maximum longitudinal deformation achievable before adherence losses, set in. The less the  
15 maximum deformation is large the smaller is the grip opposing to the inertial forces. The same scheme can be applied with any other means capable of measuring the deceleration forces.

#### Example 4

A test was made substantially as in example 1, but with a modulation in the magnetization of the two circular tape-shaped emitters. This  
20 modulation can be obtained by periodically surmounting the tapes with blocks of the same magnetic rubber with the same width, about 3.0 cm long and about 0.15 cm thick, or by cutting longer pieces of tapes, about 20 cm long, and putting them circumferentially inside the tyre as in example 1 but spaced of about 7 cm. The rubber of these blocks was  
25 charged much less than in the tapes (charging of roughly 50-100 phr). The major effect of such modulation was to induce a small variation mostly sinusoidal in the MF measured by the main sensor, and the appearance of longitudinal components of MF varying accordingly. By measuring the variations of the longitudinal component by a tri-axial  
30 main sensor the rotation of a wheel was monitored along with

accelerations and decelerations of said wheel during the traveling other than the vertical and lateral deformations. Such information was used in an ABS system. The system of the invention appeared to be suitable for this application. Assuming tyres of 40.0 cm of radius, the circumference (i.e. the length of tapes) is  $L=2.51$  m. Having a modulation wavelength of  $\lambda=L/10 \sim 25$  cm, a car running at a speed of 100 Km/h have tyres rotating with frequency  $\nu_R = 11.11$  Hz. Then the magnetic field changes with a frequency of  $\nu_L = 10\nu_R = 111.1$  Hz; therefore a sampling of few cycles, i.e. few hundredths of seconds was found to measure a variation in the angular velocity of the wheel.

#### Example 5

A test was made circumferentially positioning a tape-shaped magnetic field emitter upon the rim and another one upon the inner surface of the tyre, and precisely upon the liner, as it is shown in fig. 8. The magnetic field emitters are magnetized as disclosed in the previous examples. A SSP appeared in a radially internal position with respect to the rim in correspondence of the footprint area, displaced slightly aside with respect to those of example 1. In this test, magnetic field emitter on the rim behaved like pivot, while that on the tyre was free to move following the tyre deformations. A variation of the magnetic field following the deformation was monitored as in example 1. Such set-up can be useful in cases where size of brake disks or temperatures are an issue, or when magnetic field intensity is to be increased.

#### Example 6

A test was effected substantially analogously to that of example 5, but with three magnetic field emitters (NdFeB tapes). One of the tapes was placed upon the rim, while the other two were put upon the liner, as shown in fig. 9. In such case two SSP appeared, positioned above the rim like in example 6, but at opposite side of the brake disk. Such

configuration is interesting for ABS systems in conjunction with a modulated magnetization along the tapes.

Reference is made to Figures 10A to 10D. In those figures a frontal cross-section of two magnetic field emitters, differently magnetized, and their associated space portions SP where at least a composite magnetic field component is substantially null, are represented. Special space portions are also provided wherein special symmetry properties of the magnetic field are present, namely in the special space portions all the composite magnetic field components are null. Apparently, any space portion, because of the substantially cylinder symmetry of a tyre and a wheel (with respect to axis AX), is actually a space region substantially delimited by two parallel planes P1 and P2. At least one special space portion SSP, where all the magnetic field components are substantially null, can be comprised within the space portion SP, having a substantially toroidal-shape. In figures 10A-10D only a section of the toroidal-shaped special space portions is shown. Such a special space portion is in the space portion SP bordered by the two parallel planes. In case of non continuous magnetized emitters or in case of elongated non-continuously magnetized emitters, the special space portion SSP is an interrupted substantially toroidal-shaped space portion.

In Figures 10A and 10B the magnetization M1 and M2 of the two MF emitters is in the same direction whilst it is of different values. In principle, two substantially toroidal special space portions are created but only one (that radially internal to the tyre, the one of lower radius with respect to AX) can be exploited for placing the main sensor 102. In Figures 10C and 10D the magnetization M1 and M2 of the two MF emitters is in different directions and of different values. In this case, only one substantially toroidal shape special space portions SSP is created. Such a special space portion can be exploited for placing the



main sensor 102.

Advantageously, the main and secondary sensors 102, 103 can be connected by wire to a processing unit. The cable/wire connection can comprise a standard RS232 or CAN bus. A single secondary sensor can be provided for all the wheels of a vehicle.

CLAIMS

1. Method for monitoring deformations in a tyre of a vehicle wheel, the wheel comprising the tyre and a rim, the method comprising the steps of:

5 a) providing the wheel with at least two magnetic field emitters in mutual positions so as to yield a composite magnetic field having at least a space portion where at least a component of the composite magnetic field is substantially null, at least one of the at least two magnetic field emitters being positioned in contact with the tyre;

10 b) positioning at least one main magnetic field sensor substantially in said space portion;

c) monitoring variation of said at least one component of the composite magnetic field; and

d) correlating said variation with tyre deformations.

15 2. Method according to claim 1 wherein the at least one main sensor is positioned in a special space portion where all the components of the magnetic field are substantially null.

3. Method according to claim 1 wherein the emitters generate a composite magnetic field having an intensity ranging from 0.01 G to 10  
20 G (gauss).

4. Method according to claim 1 wherein step d) is effected by means of a linear relation.

5. Method according to claim 1 wherein step d) is effected by means of a quadratic relation.

25 6. Method according to claim 1 providing monitoring of the tyre deformations in the three spatial directions.

7. Method according to claim 1 comprising the step of positioning at least a magnetic lens in a circumferential and radially external position with respect to the MF emitters, and in radially internal position  
30 with respect to any tyre metal structure.

8. Method according to claim 1 wherein the at least one main magnetic field sensor is positioned in a non rotating portion of the wheel.

9. Method according to claim 1 comprising the step of positioning at least a secondary magnetic field sensor cooperating with the at least one main sensor.

10. System for monitoring deformations in a tyre of a vehicle wheel comprising:

a) a wheel including the tyre and a rim;

b) at least two emitters of magnetic field positioned in the wheel in mutual positions so as to yield a composite magnetic field having at least a space portion where at least a component of the composite magnetic field is substantially null, at least one of the at least two magnetic field emitters being positioned in contact with the tyre;

c) at least one main magnetic field sensor placed substantially in said space portion.

11. System according to claim 10 wherein at least one emitter positioned in contact with the tyre is positioned in the crown portion of the tyre.

12. System according to claim 10 wherein the at least two emitters are positioned in contact with the tyre.

13. System according to claim 10 wherein at least one of the at least two emitters is placed in a radial internal position with respect to any tyre metal structure.

14. System according to claim 10 wherein the at least two emitters are elongated elements.

15. System according to claim 10 wherein the at least two emitters are disposed substantially along a circumference of the wheel.

16. System according to claim 10 wherein each of the emitters has a form selected from a single piece or multiple pieces.

17. System according to claim 10 wherein the at least two magnetic

field emitters are made of magnetic rubber comprising a polymer or a polymer blend, and at least a magnetic material.

18. System according to claim 17 wherein said polymer or polymer blend has an elastic modulus at least 10% lower than the elastic modulus of the liner.

19. System according to claim 18 wherein said polymer or polymer blend is selected from halogen-butyl rubbers, for example halogenated isobutylene-isoprene (IIR) rubber.

20. System according to claim 17 wherein the at least a magnetic material is present in the magnetic rubber in an amount ranging from 50 to 400 phr.

21. System according to claim 17 wherein the at least a magnetic material is a hard magnet material.

22. System according to claim 17 wherein the at least a magnetic material has an isotropic magnetization.

23. System according to claim 17 wherein the at least a magnetic material has an intrinsic coercivity of at least 100 kA/m.

24. System according to claim 17 wherein the at least a magnetic material has a residual induction ( $B_r$ ) higher than 0.6 T (Tesla).

25. System according to claim 17 wherein the at least a magnetic material has a Curie temperature greater than 300°C.

26. System according to claim 10 wherein the emitters are magnetized uniformly.

28. System according to claim 10 wherein in the emitters a magnetization modulation is induced.

29. System according to claim 10 comprising at least a magnetic lens.

30. System according to claim 29 wherein the magnetic lens comprises soft magnetic material.

31. System according to claim 29 wherein a single magnetic lens is

provided for the at least two magnetic field emitters

32. System according to claim 10 wherein the at least one main magnetic field sensor is positioned in a non rotating portion of the wheel.

5 33. System according to claims 10 wherein the at least one main magnetic field sensor is monoaxial, bi-axial or tri-axial.

34. System according to claim 10 comprising at least a secondary magnetic field sensor.

10 35. System according to claim 34 wherein said at least a secondary sensor is located at least 20 cm far from the at least one main sensor.

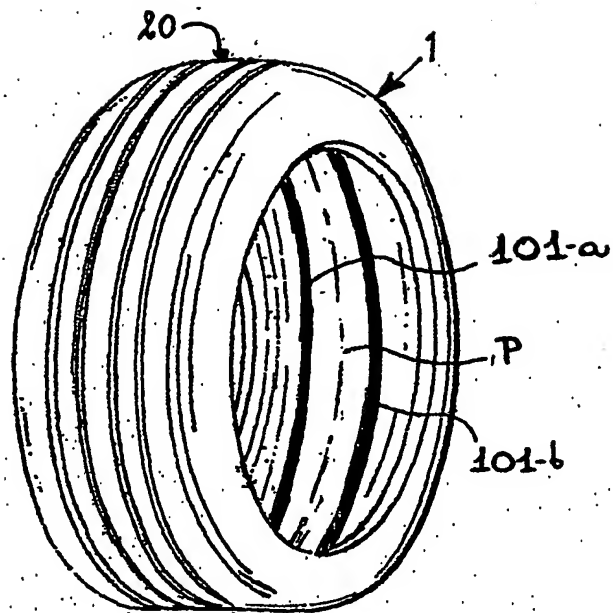
36. System according to claim 34 wherein said at least a secondary sensor is located at a distance smaller than 3 cm from the at least one main sensor.

15 37. System according to claim 34 wherein said at least a secondary sensor cooperates with multiple main sensors.

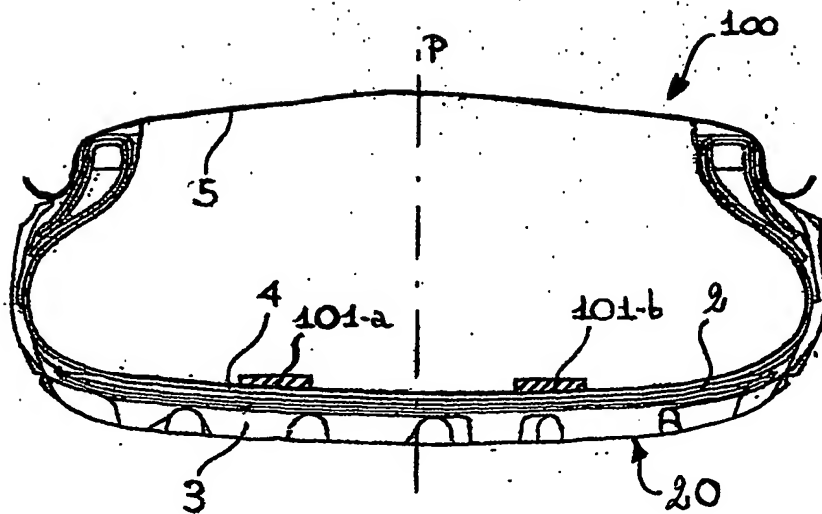
38. System according to claims 34 wherein the at least a secondary sensor is monoaxial, bi-axial or tri-axial.

20 39. System according to claim 34 wherein said secondary sensor is oriented substantially analogously to the corresponding main sensor/s.

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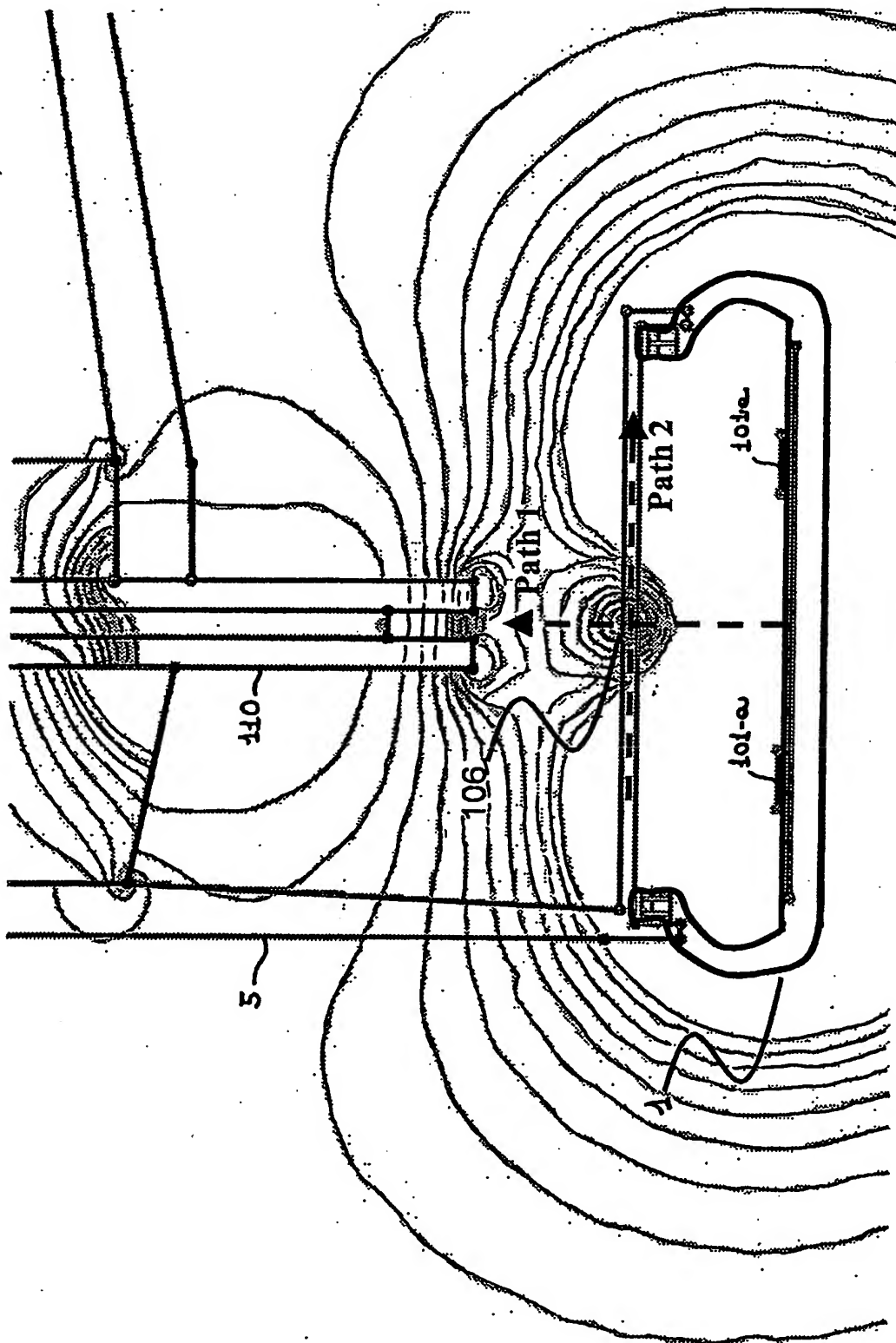
**Fig. 1**



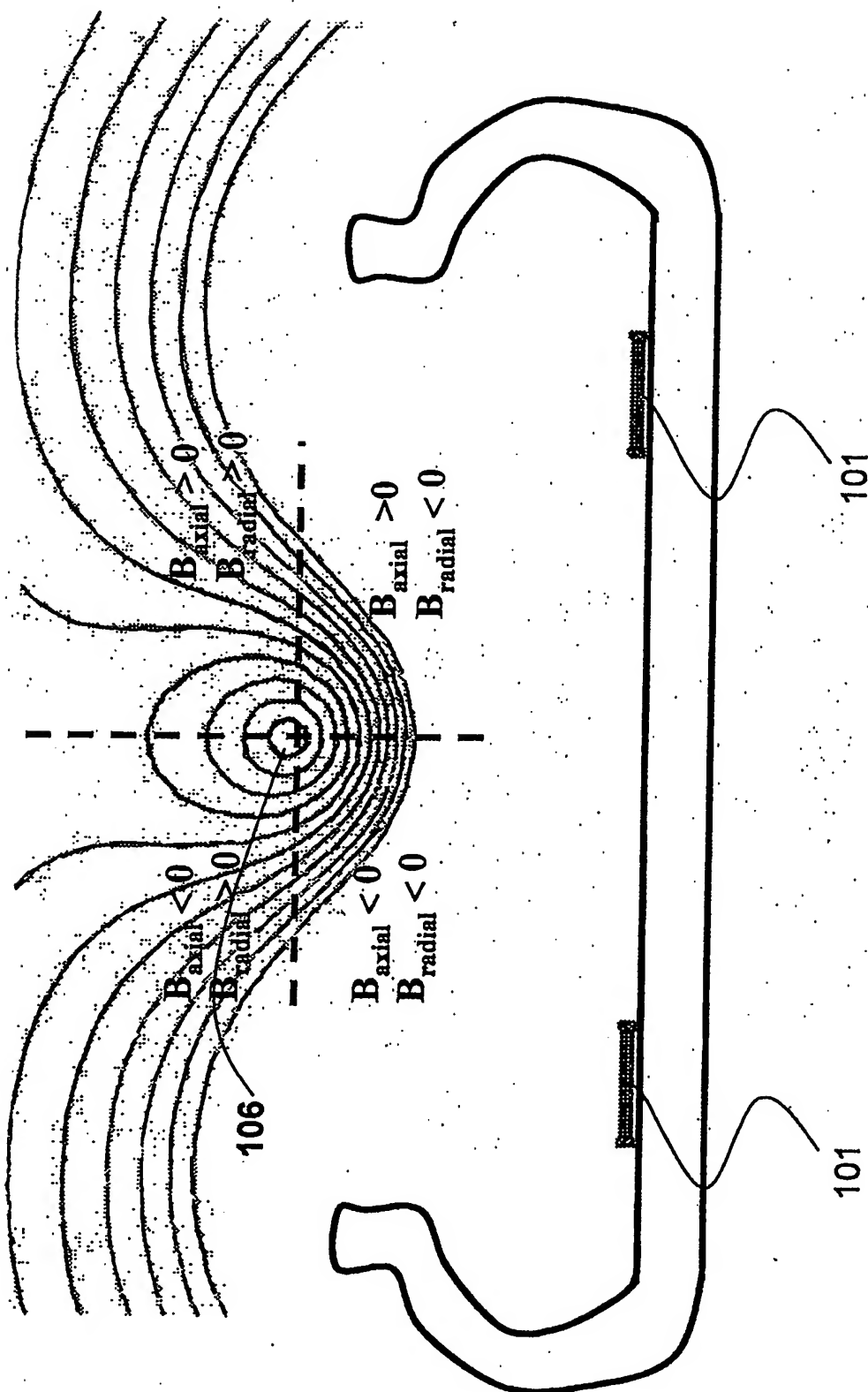
**Fig. 2**

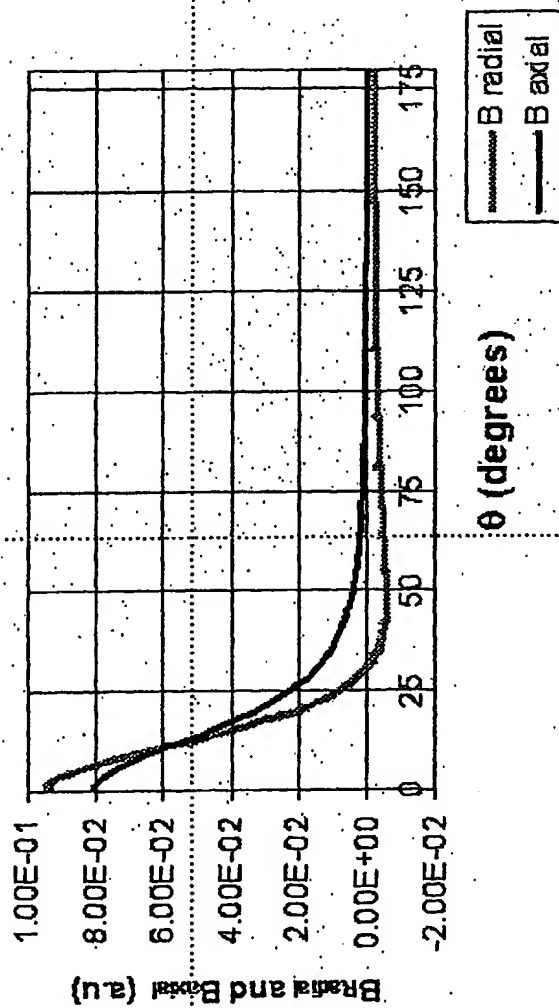


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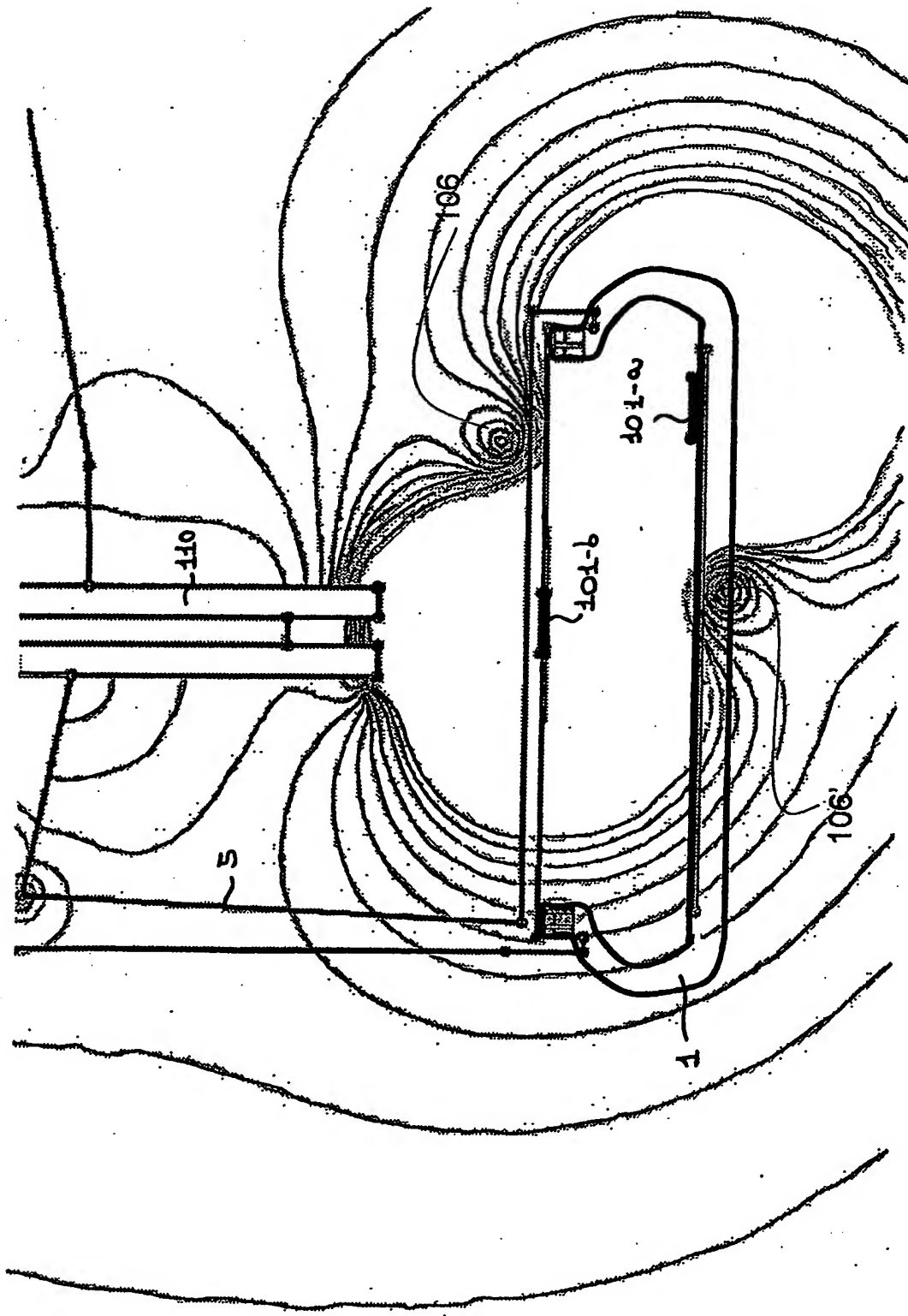




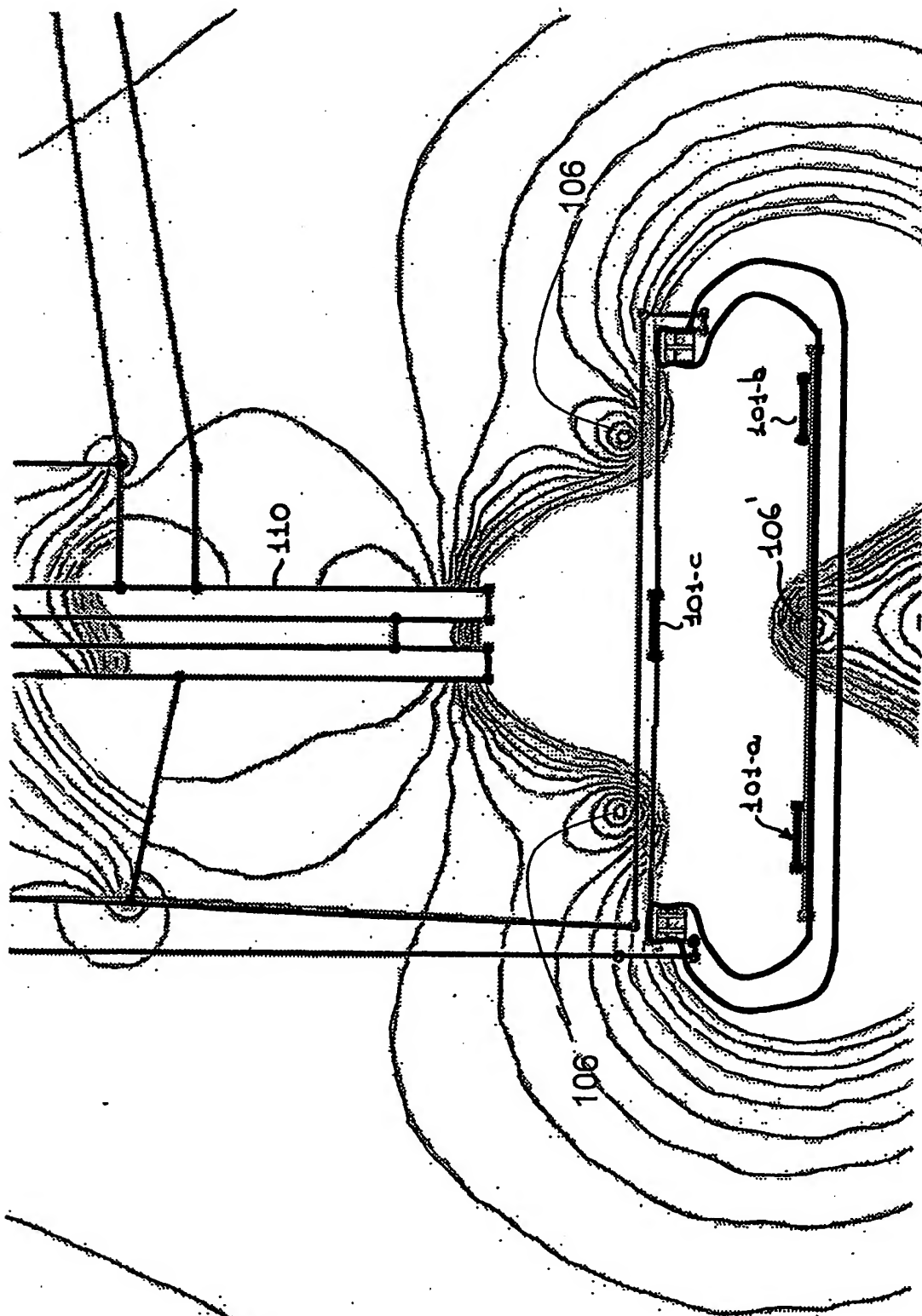
**Fig. 6**

**Fig. 7**

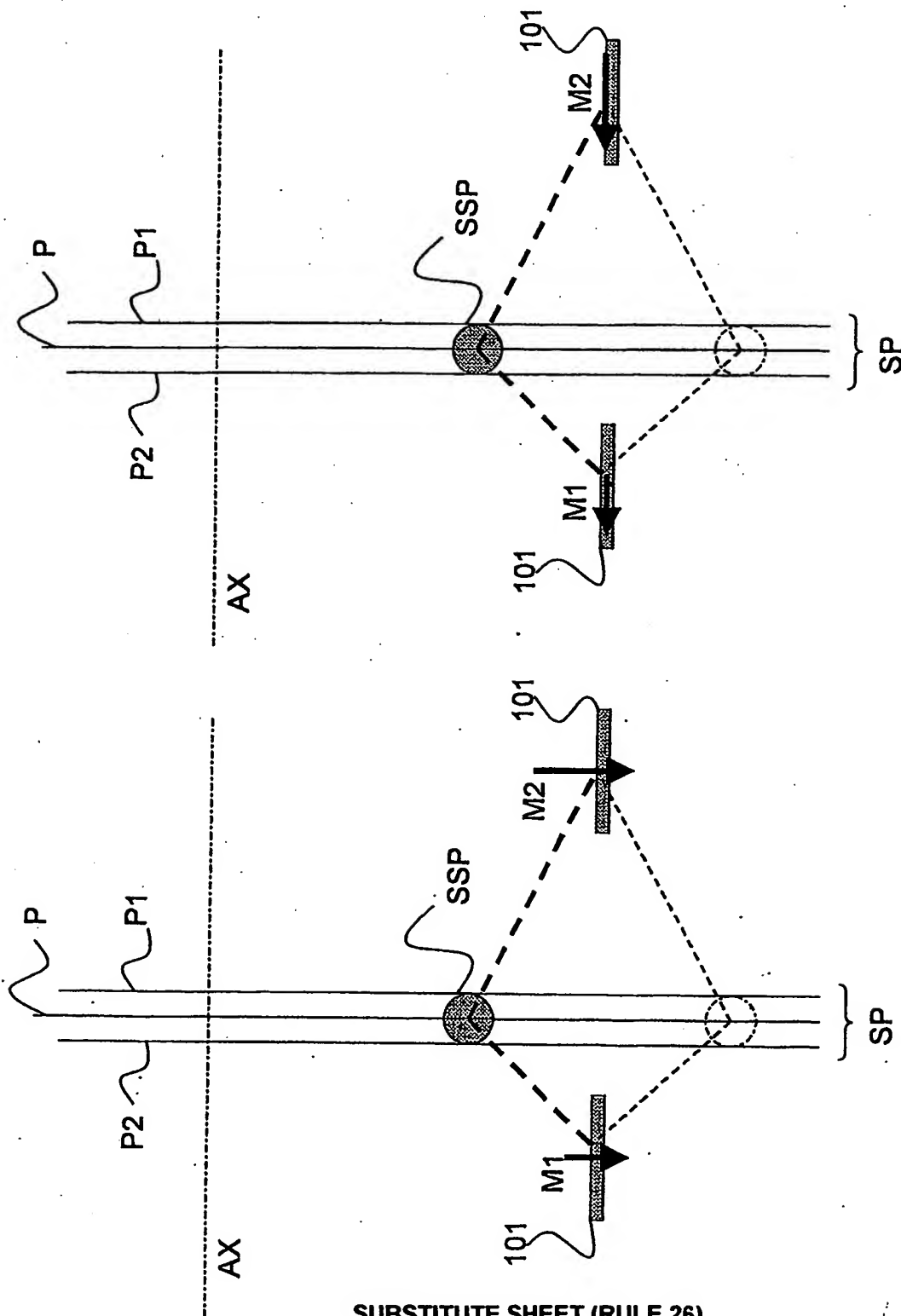
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**Fig. 8**



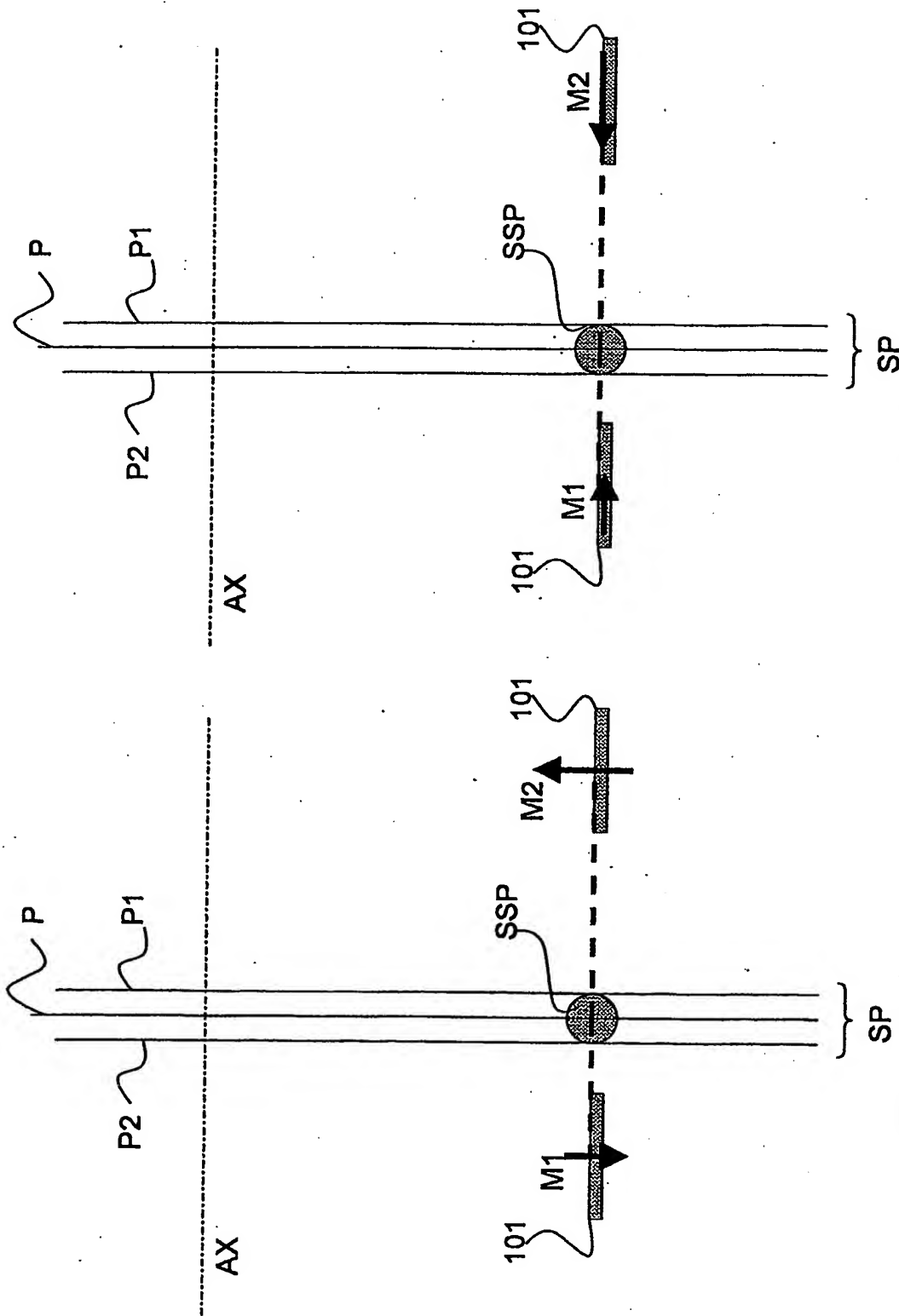
**Fig. 9**



**Fig. 10B**

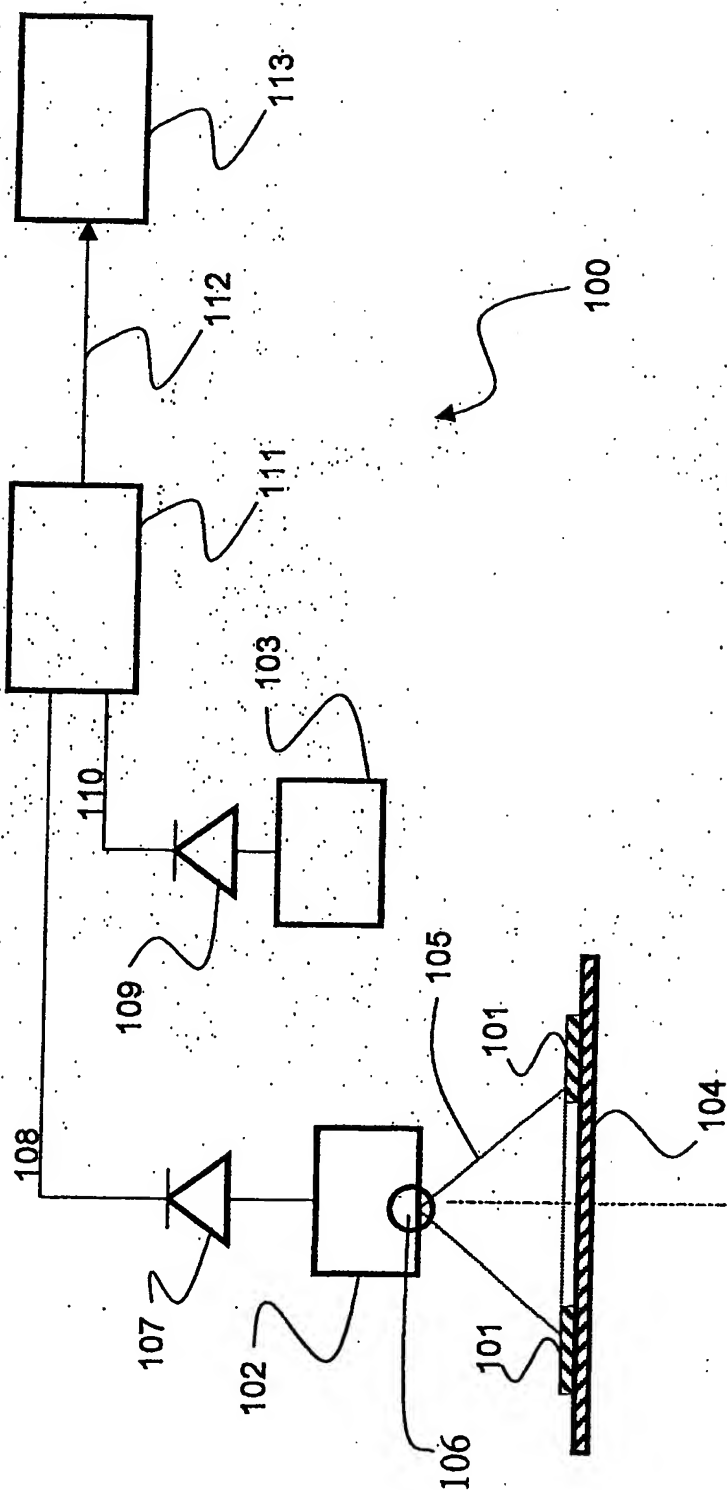
**Fig. 10A**

9/10



**Fig. 10D**

**Fig. 10C**



**Fig. 11**

# INTERNATIONAL SEARCH REPORT

International Application No.

PCT/EP 03/10505

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 7 B60T8/00

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 B60T B60C G01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 01/94168 A (PIRELLI ; BELLUZZO DAMIANO (IT); MANCOSU FEDERICO (IT); MATRASCIA GIUS) 13 December 2001 (2001-12-13) abstract figure 2	1,10
A	US 5 964 265 A (BECHERER THOMAS) 12 October 1999 (1999-10-12) cited in the application the whole document	1,10



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

\* Special categories of cited documents:

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search

15 April 2004

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International Application No

PCT/EP 03/10505

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 0194168	A	13-12-2001	AU 7843801 A	17-12-2001
			BR 0111491 A	25-03-2003
			WO 0194168 A1	13-12-2001
			EP 1289813 A1	12-03-2003
			US 2003159503 A1	28-08-2003
US 5964265	A	12-10-1999	DE 19646235 C1	02-04-1998
			EP 0841550 A2	13-05-1998